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PHYTOINDICATION IS AN EFFECTIVE METHOD FOR ACCURATELY DETERMINING THE LIGHTING INTENSITY IN URBAN PARKS

OLENA LISOVETS[1], OLGA KUNAKH[2], HANNA TUTOVA[3], OLEXANDER ZHUKOV ✉[4]

[1]Department of Geobotany, Pedology, and Ecology, Faculty of Biology and Ecology, Oles Honchar Dnipro National University, Gagarin Ave. 72, 49010 Dnipro, Ukraine; e-mail: lisovetselena@gmail.com
[2]Department of Zoology and Ecology, Faculty of Biology and Ecology, Oles Honchar Dnipro National University, Gagarin Ave. 72, 49010 Dnipro, Ukraine; e-mail: kunah_olga@ukr.net
[3]Department of Botany, Ecology and Horticulture, Bogdan Khmelnitsky Melitopol State Pedagogical University, Hetmanska st., 20, Melitopol, 72318, Ukraine; annatutova37@gmail.com
[4]Department of Botany, Ecology and Horticulture, Bogdan Khmelnitsky Melitopol State Pedagogical University, Hetmanska st., 20, Melitopol, 72318, Ukraine; zhukov_dnipro@ukr.net

✉ Corresponding author

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Abstract

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This study demonstrates the potential for utilising the phytoindication approach to ascertain the light regime of urban park plantations and evaluates the efficacy of the weighted average and ideal indicator methods for the phytoindication of light regimes. The study was conducted in two urban parks in the city of Dnipro, Ukraine. A total of 128 plant species were identified within the vegetation of the parks. A strong correlation was observed between the instrumental and phytoindication-based estimates of light intensity within the parks. The weighted average method yielded underestimates in comparison to instrumentally measured values across the range of light gradients from medium to high. The accuracy of the phytoindication estimates decreased monotonically with increasing number of species in the relevé, from 7 to 8 and above, and reached a plateau when the number of species exceeded 15. The expansion of hemeroby was observed to be correlated with an increase in the light intensity of the parkland, which is well explained by the Hill saturation curve. The natural urban park communities presented relatively lower light levels. This correlation demonstrates a linear trend.

Key words: urbanisation, hat island, diversity, plant community, phytoindication, hemeroby, naturalness, ideal indicator.

Introduction

The urban climate is significantly altered by a number of factors, including the population concentration, increased building density, industrial processing and destruction of natural vegetation (Ribeiro et al., 2019). The deterioration of human life and biota conditions in urban areas is significantly influenced by a range of environmental factors, including chemical (Mandaric et al., 2018), acoustic (Haselhoff et al., 2023) and heat pollution (Piracha, Chaudhary, 2022). Industrial enterprises, transportation systems and buildings are identified as sources of heat pollution in urban areas (Shahmohamadi et al., 2011). A reduction in vegetation cover has a marked impact on the albedo of urban surfaces, which in turn exerts a considerable influence on a city's heat balance (Lopez-Cabeza et al., 2022). The establishment of urban green spaces can lead to a notable enhancement of the urban environment, as well as an increase in visitor numbers for recreational purposes, due to the favourable conditions that such spaces offer (Halecki et al., 2023). Tree plantations in urban parks provide a wide range of ecosystem services, which are a derivative of the so-called 'pertinence' (Vysotsky, 1925), that is, the ability of natural and artificial forest vegetation to change microclimatic conditions. The objective of urban park management should be to stimulate the functioning of ecosystem services (Mexia et al., 2018). Consequently, any management strategies must be founded upon quantifiable indicators. One significant objective in the management of urban parks is the regulation of the light regime. The lighting regime affects the thermal conditions of a park (Abuseif, 2023), the availability of light for plants, and the soil and air humidity (Supronowicz, Fryc, 2019). These regimes serve to establish favourable conditions for the biota, which constitute the core of the park. Furthermore, the light regime of a park impacts the comfort of park visitors (Smith, Hallo, 2019) but no studies have investigated visitor preferences for lighting in these locations, nor reasons for such preferences. Visitors' preferences for lighting may help parks regulate and utilize lighting in a way that both protects resources and provides for quality night experiences. Brightness, Correlated Color Temperature (CCT.

The light regime can be evaluated through utilisation of instrumental measurements or phytoindication. Each approach has its own set of advantages and disadvantages. While instrumental measurements offer technically accurate results, they may not always be ecologically relevant. It is unclear whether a study of light measurements in space and time, which would provide comprehensive information on the impact of environmental factors on vegetation cover, is theoretically feasible. Even if such studies are feasible, they are unlikely to be widely adopted in practice. Nevertheless, the efficacy of phytoindication in yielding precise outcomes must be evaluated through a comparative analysis with data obtained through instrumental measurement. The use of phytoindication to assess environmental factors offers a number of significant advantages (Molozhon et al., 2023). The method is straightforward and yields results that are relevant to the natural environment. Vegetation can be considered a 'memory unit', in that it records information about environmental processes in its structure. This information can be obtained through the process of phytoindication. Importantly, the majority of indicator values are associated with species behaviour, particularly in relatively stable forest ecosystems and in the subsequent meadows, wetlands and other communities that were prevalent in Central Europe during the determination of the indicator values (Dzwonko, 2001). The mean values of the Ellenberg indicators for light, reaction and nitrogen were found to be relatively effective predictors of ecological conditions in old-growth forests with a stabilised species composition, which was determined primarily by the ecological regime. Nevertheless, they have been found to be considerably less effective indicators in young forests (Dzwonko, 2001). The question of the feasibility of employing the phytoindication method in the context of urban parks remains unanswered.

The concept of hemeroby is a useful tool for studying the extent of anthropogenic transformation in urban ecosystems (Battisti, Fanelli, 2016). The hemeroby scale is the most sensitive tool for distinguishing between ecosystems that are subjected to considerable anthropogenic pressure (Hill et al., 2002). The concept of hemeroby is complementary to that of naturalness, which is an effective framework for planning protection measures and monitoring the state of protected areas (Sengl et al., 2017). The conditions of urban parks are subject to considerable anthropogenic pressure. Therefore, hemeroby is an appropriate tool for assessing their suitability for human habitation. Furthermore, parks serve as hubs for biodiversity, encompassing fragments of ecosystems that closely resemble their natural state. This is the rationale behind the utility of the naturalness scale in assessing the condition of park plantations. The relationships among light conditions, hemeroby and naturalness are of both scientific and practical interest.

In the practice of phytoindication, two distinct types of indicators are employed: modal and range scales. One of the most commonly used modal scales in Europe is the Ellenberg indicator system (Ellenberg, 1979). These scales indicate the conditions that are most favourable for the plant species in question, and the environmental factor score is usually calculated as a weighted average of the indicator values for all plant species in the geobotanical relevé. The range scale is used in the Didukh system (Didukh, 2011). These scales indicate the range of conditions under which a species can exist. The range scales allow for the application of the weighted average method as well as the ideal indicator method (Buzuk, 2017).

The objectives of this study were to address three key issues: 1) to test the feasibility of utilising the phytoindication approach to ascertain the light regime of urban park plantations, 2) to evaluate the efficacy of the weighted average and ideal indicator techniques for the phytoindication of the light regime and 3) to ascertain the influence of hemeroby and naturalness on the precision of phytoindication of the light regime in urban parks.

Material and methods

The study was conducted in two parks in the city of Dnipro (Ukraine). The areas of Ivan Starov Square and Students' Park were 11.2 ha each. Ivan Starov Square is located in the historical centre of the city and is subject to a significant recreational load. Students' Park is located within the campus of Oles Honchar Dnipro National University and is subject to a much lower recreational load. The vegetation cover of Ivan Starov Park was represented by two layers: trees and herbaceous plants. A total of 44 species of trees were found in the tree stands of both parks. The tree stand represented 33 tree species, among which (in descending order of abundance) *Robinia pseudoacacia*, *Ulmus pumila*, *Acer platanoides*, *Tilia platyphyllos*, *Styphnolobium japonicum*, *Aesculus hippocastanum* and *Fraxinus pennsylvanica* prevailed. The tree stand crown closure was 0.61 ± 0.25. The vegetation cover of Students› Park was represented by three tiers: tree, shrub and grass. The tree stand was represented by 27 tree species, among which the following predominated (in descending order of representation): *Robinia pseudoacacia, Acer platanoides*, *Acer negundo*, *Gleditsia triacanthos*, *Aesculus hippocastanum*, *Populus carolinensis* and *Fraxinus pennsylvanica.* The tree stand crown closure was 0.70 ± 0.09. The shrub layer was represented by 16 species, among which *Sambucus nigra*, *Crataegus fallacina* and *Euonymus europaeus* prevailed.

The sample locations were distributed throughout the study area, and their exact locations were determined via GPS (Garmin eTrex, ±5 m). In Ivan Starov Square, vegetation cover was recorded and environmental properties were measured at 150 locations in a quasiregular grid (Fig. 1). Ivan Starov Park occupies a relatively flat area with relief heights ranging from 115 to 128 m. In addition, management measures in the park are relatively uniform. The survey density in Ivan Starov Square was one location per 748 m^2. Students' Park covers a much more geomorphologically diverse area. The relief height within this park ranges from 131 to 165 m. In addition, the territory of the park has been partially reconstructed (Zhukov et al., 2023; Molozhon et al., 2023). The density of the recording points was increased to account for this heterogeneity. In Students' Park, vegetation cover and environmental measurements were taken at 230 locations on a quasiregular grid, and the survey density was one location per 501 m^2.

The presence of all species of vascular plants in the herbaceous layer on the 3×3 m test plots was recorded during the study period, which spanned from 7 to 12 July 2024. The projected species cover of the plants is indicated as a percentage. In the context of this study, the term ‹species› is typically used to refer to infrared taxa. Critical specimens were collected and identified by microscopy. The plant taxonomy was based on the Euro+Med Plantbase (http://ww2.bgbm.org/EuroPlusMed).

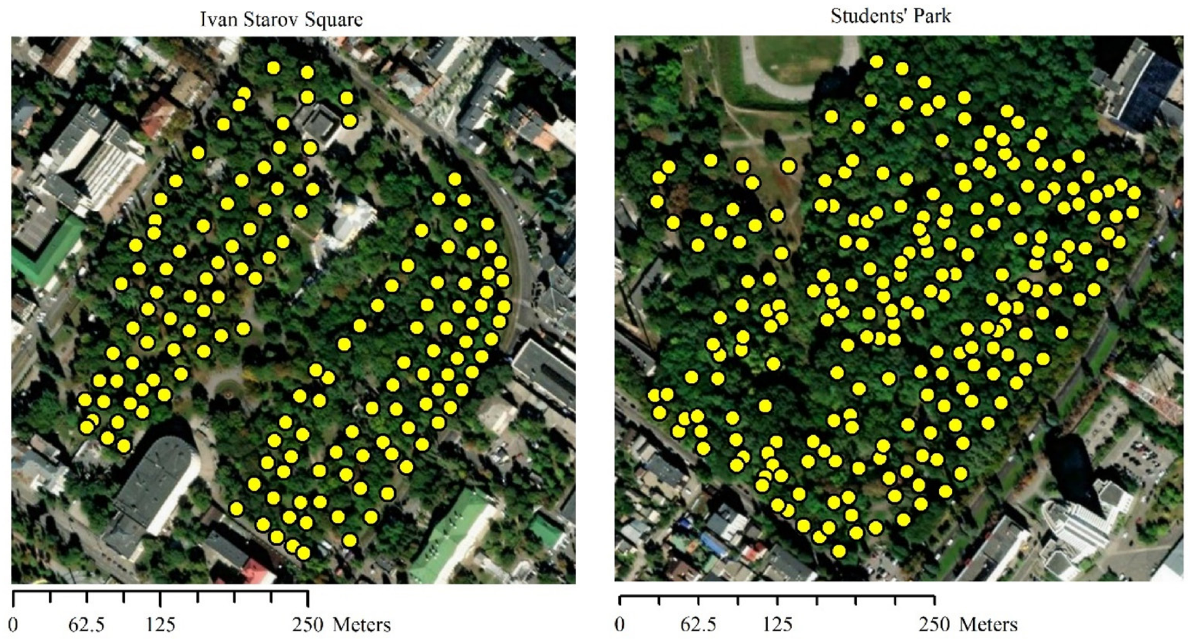

Fig. 1. Locations of lighting measurements and plant recording locations in Ivan Starov Square and Students' Park (Dnipro, Ukraine).

Determination of light levels is typically based on the relative illumination of the plots during the growing season. This is defined as the light prevailing in the species' habitat during the period of full foliage of deciduous plants (i.e. July to September) under diffuse light (i.e. fog or uniformly cloudy skies). The light intensity was quantified at four points in each plot using a lux meter calibrated in lux, and the resulting values were averaged and expressed as a percentage of the light intensity in the open space (Dzwonko, 2001). The light intensity measurements at the study locations were carried out between 10 am and 2 pm. At the same time, an observer was in the open area, and also the light level was measured. In relation to the level of illumination in the open area, the percentage of illumination in the study location was estimated at the appropriate time.

The Ellenberg light indicator values, which fall within the range of 1–9, are as follows: 1) plants of the deep shade category, which are still less than 1% and, on occasion, greater than 10% relative light; 2) species that fall between categories 1 and 3; 3) plants of the shade category, which are mostly able to tolerate conditions with less than 5% relative light; 4) species that fall between categories 3 and 5; 5) plants of the semishade category, which are able to survive at greater than 10% relative light, but on occasion, in full light; 6) species intermediate between 5 and 7; 7) plants of habitat with high light intensity that can tolerate partial shade; 8) high light plants, occasionally found at <40% relative light and 9) full light plants, which are found mainly in full light, occasionally at <50% light (Ellenberg, 1979). The indicator values given in Dengler et al. (2023) were used for the calculations. Theoretically, the relationship between the measured light and the phytoindicative assessment of the light level is as follows:

$$\text{log\_Lighiting} = 0.22 * L\text{-value}, \tag{1}$$

where log_Lighiting is the decimal logarithm of the relative light level and L-value is the phytoindication assessment of the light level according to the Ellenberg scale.

The phytoindication value of the environmental factor is calculated as the average of the indicator values of the species in the relevé, which is weighted taking into account the abundance of the plant species (Ter Braak, Barendregt, 1986; Zelený, Schaffers, 2012). The projected cover of plant species was used as a weight in the calculation of the phytoindication assessment of lighting (Šmilauer, Lepš, 2014):

$$\mathrm{WA} = \frac{\sum_{i=1}^{n} L\text{-value}_i \times Pr_i}{\sum_{i=1}^{n} Pr_i}, \tag{2}$$

where $L\text{-value}_i$ is the indicator value of the i-th species and Pr_i is the projective cover of the i-th species in the relevé.

The range indicator scale was developed by Didukh (2011) for lighting indications. This scale is based on the Ellenberg scale, but it provides the minimum and maximum values of the ecological range in which the species can occur. In terms of calculation, Didukh determined the mean value between the minimum and maximum values of his scale, thereby obtaining the Ellenberg scale. The resulting indicator values were also subjected to average weighting, as is customary in the Ellenberg method. Didukh made the following remark: evidently, the mean values of the amplitude scale cannot be 1 or 9, given that ultrasciophytes have an index of less than 3 and heliophytes have a score greater than 7 during the calculation (Didukh, 2011). This disadvantage is not present in the ideal indicator method (Buzuk, 2017), which fully uses information on the ecological range of a species for phytoindication. The ideal indicator method can be applied only to data on the occurrence of plant species and does not consider information on the projected plant cover. We have proposed an improvement in this approach (Zhukov et al., 2018). In the fol-

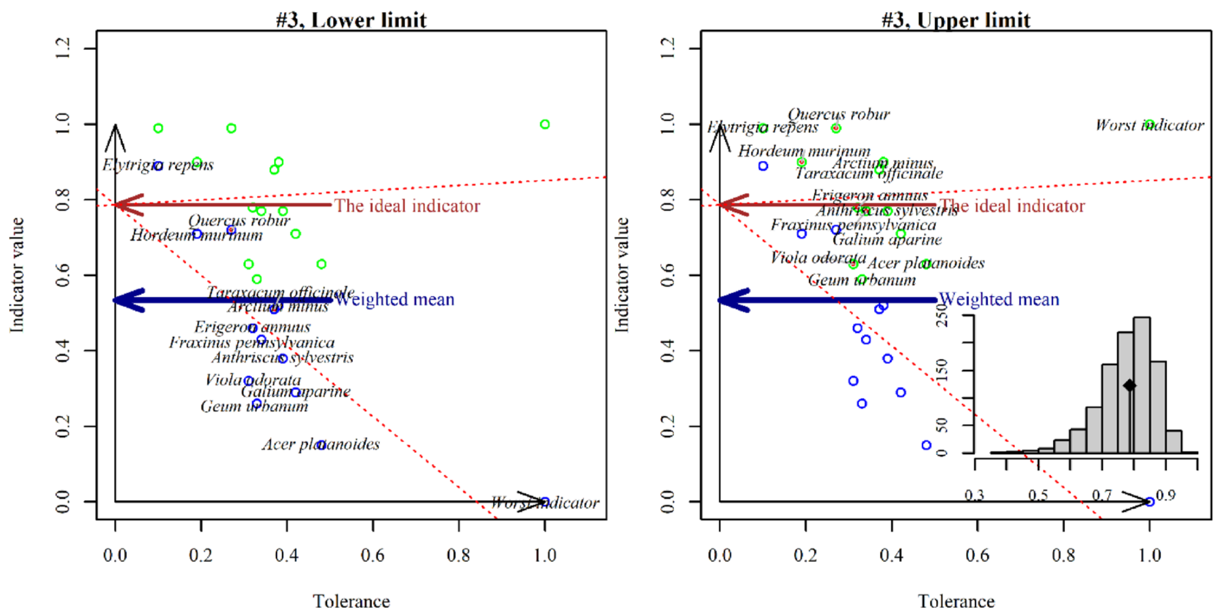

Fig. 2. Comparison of the weighted average method (traditional Ellenberg approach) and the ideal indicator method, which uses the capabilities of Didukh range scales (relevé #3 from Students' Park). The abscissa axis represents the species tolerance, estimated as the difference between the maximum and minimum indicator values (normalised to 1). The ordinate axis shows the maximum and minimum indicator values (for convenience, the left figure shows species names for the minimum indicator values and the right figure shows the maximum indicator values). The indicator values are normalised to the range 0–1. The imaginary 'worst case' indicator species has a tolerance of 1 (maximum) and indicates all possible conditions. For the minimum and maximum amplitude values of the species in the description, approximation lines are calculated that converge on the ordinate axis, that is, correspond to the ideal state with zero tolerance. Zero tolerance can be achieved by an ideal species that can exist only under the conditions of a given location, which is thus an ideal indicator. The weighted average usually gives a biased value that tends to be closer to the centre of the factor gradient.

lowing text, the estimates obtained using the weighted average of indicator values are denoted as Ellenberg estimates and the estimates based on amplitude scales using the ideal indicator method are denoted as Didukh estimates (Fig. 2).

The Frank and Klotz scale was used to assess hemeroby (Frank, Klotz, 1990). The original scores were converted by calculating the half-sum of the minimum and maximum values for each species and then converted to a 100-point scale (Kunakh et al., 2024). The weighted average of the hemeroby scores, taking into account the projected cover of each plant species, was used to characterise the hemeroby of each sample (Yorkina et al., 2022; Podpriatova et al., 2023). The social behaviour of plants is contingent upon the role that a given species plays within a community. Such behaviour is indicative of the manner in which the plant is integrated into the surrounding habitat, as well as the informational content and naturalness of this integration. The characteristics of the species present in a community can be employed to ascertain the richness of ecological information, the stability and naturalness of the community, the degree of niche filling, the regeneration capacity or capacity of the community and the degree of disturbance, transformation or deviation from the natural state (Borhidi, 1995). The weighted average value of the scales of plant social behaviour types was utilised for the purpose of analysing the naturalness of each sample, with due consideration given to the projected coverage of plant species (Yorkina et al., 2022).

Hill's equation was used to explain the functional dependence of the lighting regime on the level of hemeroby (Hill, 1910):

$$Y = \frac{M}{1 + (\frac{K}{x})^n}, \qquad (3)$$

where Y is the dependent variable; x is the function argument; M, K and n are coefficients; n is the Hill coefficient, which is a measure of hypersensitivity or how steep the response curve is, and K is the level of the factor at which half the response of the function is observed. Calculations were made via nonlinear estimation from the StatSoft software (StatSoft Inc., 2014).

Results

A total of 128 plant species were identified within the vegetation of the parks. The number of species was found to be positively correlated with light intensity ($r = 0.33$, $P < 0.001$) and hemeroby ($r = 0.18$, $P < 0.001$). The flora of Ivan Starov Square was found to comprise 63 species of plants, with *Lolium perenne*, *Hordeum murinum*, *Poa angustifolia*, *Polygonum aviculare*, *Dactylis glomerata* and *Taraxacum officinale* being the most prevalent. Ninety-nine species of plants were found in Students' Park, with *Chelidonium majus*, *Impatiens parviflora*, *Viola odorata*, *Ballota nigra*, *Anthriscus sylvestris* and *Geum urbanum* being the most prevalent. The intensity of lighting in Ivan Starov Square was ob-

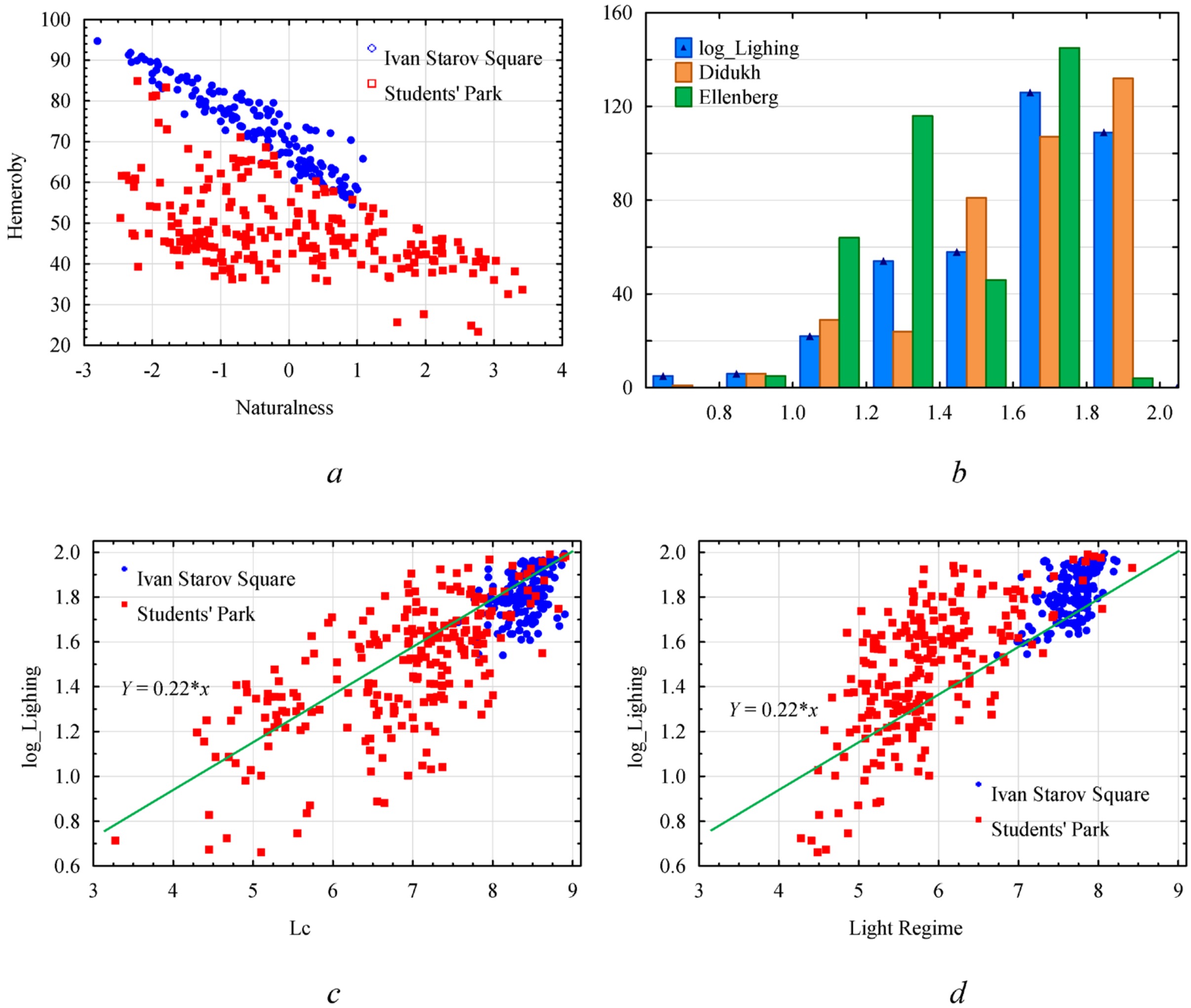

Fig. 3. (*a*) Correlation between hemeroby and naturalness in Starov Square ($r = -0.96$, $P < 0.001$) and Student's Park ($r = -0.66$, $P < 0.001$), and histograms of the distribution of measured values of light intensity (log_Lighing as % after log transformation) of phytoindication estimates of light intensity according to Didukh (0.22*Lc as % after log transformation) and Ellenberg (0.22*Light Regime as % after log transformation). (*b*) Correlation between Didukh phytoindication assessment of light regime and measured illumination (on a logarithmic scale, *c*) in Starov Square ($r = 0.43$, $P < 0.001$) and Student's Park ($r = 0.67$, $P < 0.001$). Correlation between Ellenberg phytoindication assessment of light regime and measured illumination (on a logarithmic scale, *d*) in Starov Square ($r = 0.52$, $P < 0.001$) and Student's Park ($r = 0.66$, $P < 0.001$).

served to be 64.7 ± 1.3%, with a range of 34.8–98.8%. The light intensity in Students' Park was found to be 30.0 ± 1.9%, with a range of 4.6–97.9%. The observed differences in lighting between the facilities were statistically significant ($t = 14.1$, $P < 0.001$). The hemeroby of the plant communities in Ivan Starov Square was statistically significantly greater (72.8 ± 9.9) than that of the plant communities in Students› Park (48.5 ± 10.0) ($t = 23.2$, $P < 0.001$). It is reasonable that the naturalness of the plant communities in Ivan Starov Square was statistically significantly lower (–0.44 ± 0.91) than that of this indicator for the plant communities in Students› Park (–0.02 ± 1.21) ($t = 3.1$, $P = 0.002$). Hemeroby was negatively correlated with naturalness both for the plant communities in Ivan Starov Square ($r = -0.96$, $P < 0.001$) and in Students' Park ($r = -0.66$, $P < 0.001$) (Fig. 3a).

Didukh phytoindication assessment of lighting intensity in Ivan Starov Square yielded a mean value of 8.4 ± 0.3, with a range of 7.6–9.0. Didukh phytoindication assessment of light intensity in Students' Park yielded a mean value of 6.9 ± 1.1, with a range of 3.3–8.9. The discrepancies in illumination levels, as determined by phytoindication assessments, were found to be statistically significant across these locations ($t = 17.1$, $P < 0.001$). The phytoindication assessment of light intensity according to Ellenberg in Ivan Starov Square was 7.7 ± 0.3, with a range of 6.7–8.2. The phytoindication assessment of light intensity by Ellenberg in Students' Park yielded a mean value of 5.9 ± 0.8, with a range of 4.3–8.4. The differences in lighting according to the phytoindication assessments between the two sites were statistically significant ($t = 27.8$, $P < 0.001$). Didukh's assessment of lighting conditions was greater than Ellenberg's assessment ($t = 10.6$, $P < 0.001$).

Comparison of the distribution of light intensity values obtained via instrumental measurements and phytoindication val-

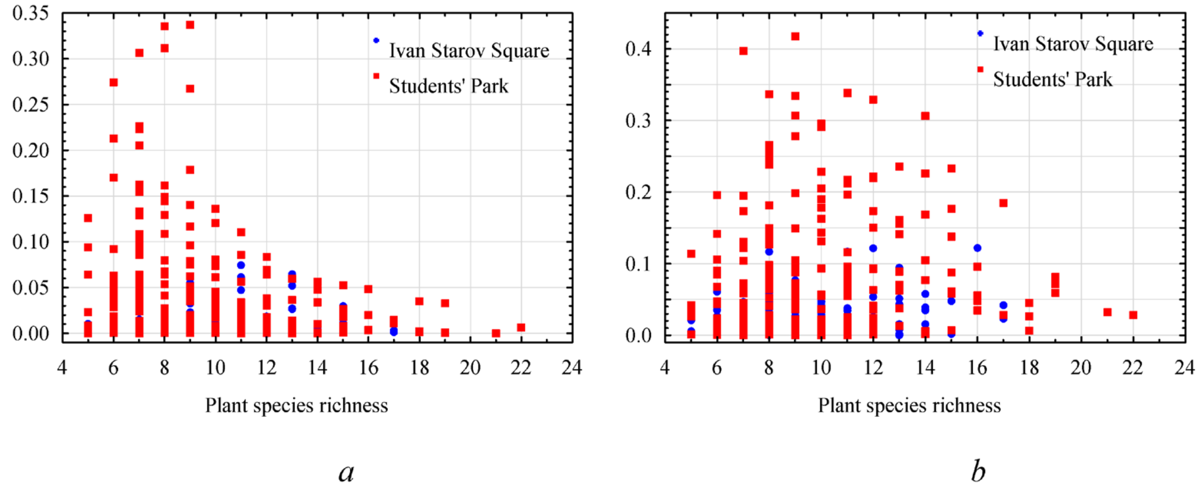

Fig. 4. Square of deviation between instrumentally measured light intensity and predicted light intensity according to the regression model based on phytoindicator scores by Didukh (*a*) and Ellenberg (*b*).

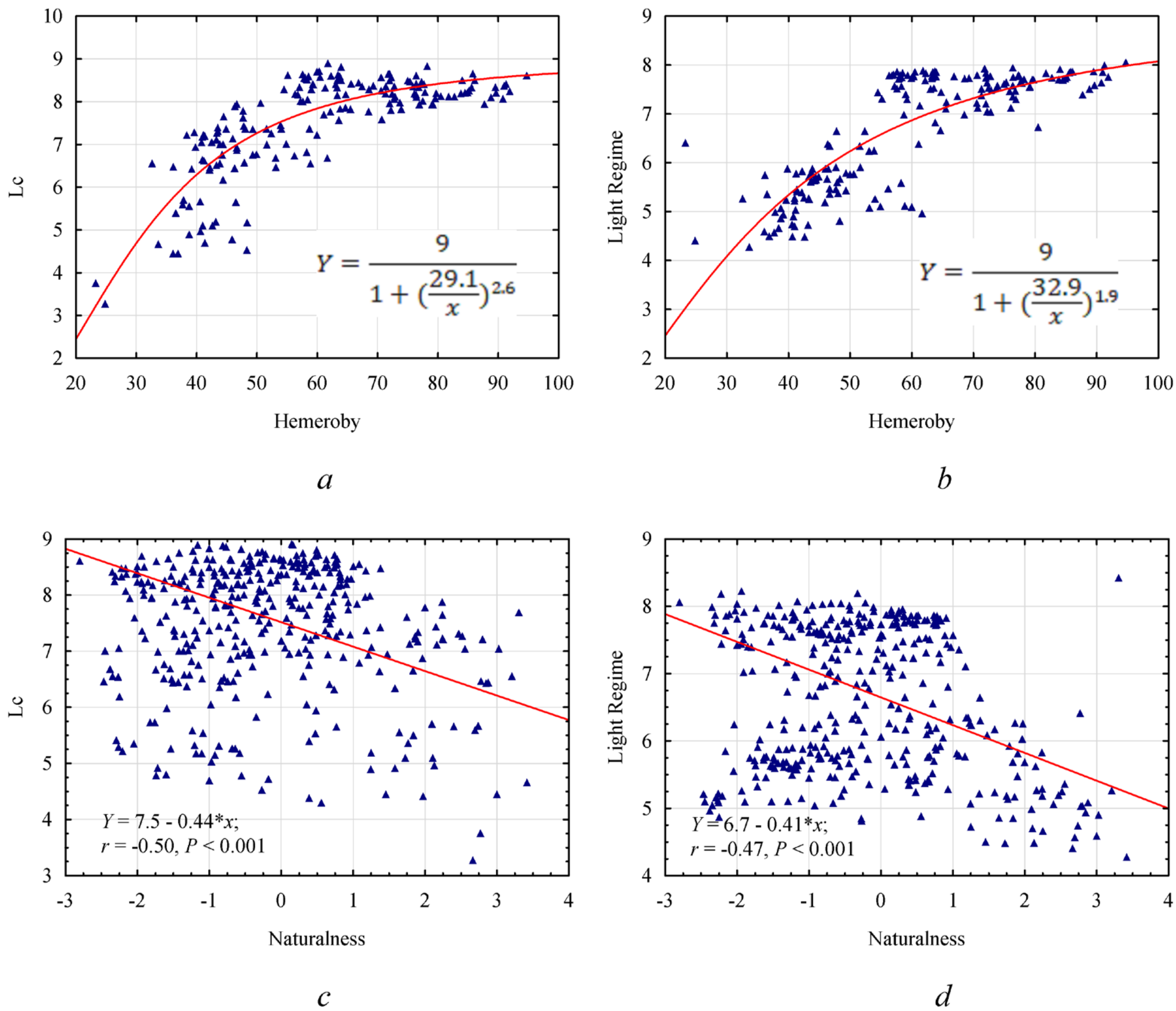

Fig. 5. Hill's dependence of the Didukh (*a*) and Ellenberg (*b*) phytoindication assessment of the lighting regime on hemeroby and the linear dependence of the Didukh (*c*) and Ellenberg (*d*) phytoindication assessment of the lighting regime on naturalness.

ues, which were rescaled to instrumental measurement units, revealed a good agreement between the instrumental and Didukh values under high light conditions (Fig. 3b). The phytoindication values were statistically significantly correlated with the measured values of light intensity (Fig. 3c, d). Compared to the instrumentally measured values, the weighted average method underestimates values in the range of light gradients from medium to high values. This is evident from both the histogram (Fig. 3b) and the scatter plot (Fig. 3d).

Didukh phytoindication accounted for 61.8% of the variability in the measured light levels ($F = 611.2$, $P < 0.001$), whereas the Ellenberg score explained 55.2% of the variability in the measured light levels ($F = 467.7$, $P < 0.001$). The square of the deviation between the instrumentally measured light intensity and the phytoindication score was found to depend on the number of species in the inventory (Fig. 4). In the case of Didukh index values, the greatest square deviation decreased monotonically with the number of species in the relevé, with values ranging from 7 to 8 and above, reaching a plateau when the number of species exceeded 15. A comparable pattern was evident in the case of the Ellenberg values, albeit with a somewhat slower decline in the trend of decreasing deviation squares.

The observed increase in hemeroby was found to be associated with an increase in light intensity, which can be well explained by a saturated response curve (Fig. 5a, b). Hill›s constant indicates that the response curve of light evaluations according to Didukh is more curved than that according to Ellenberg. Importantly, the coefficient K of the response curve for the instrumentally measured light intensity was 29.6, whereas Hill's coefficient n was 2.4. Therefore, the Didukh response curve was more similar in shape to the response curve of light intensity based on the results of instrumental measurements than the Ellenberg response curve. The data indicated that more natural communities presented lower light levels (Fig. 5c, d). A linear trend was evident in this correlation.

Discussion

The parks under examination exhibit a gradient of hemeroby and naturalness. In Students' Park, communities exhibiting a relatively high degree of naturalness (i.e. greater than 1) have been retained. There are a number of reasons for the preservation of natural communities. Following the Second World War, tree plantations were established in Students' Park to imitate a natural oak forest, the remnants of which can still be observed within the park. In the steppe zone, oak woodland vegetation is typically found in depressions in the terrain, such as gullies. The park's challenging terrain has contributed to the preservation of natural vegetation, as the steep slopes of the gully restrict visitor access and mitigate recreational pressure (Moravčík et al., 2024). The territory of Ivan Starov Square has been subjected to significant anthropogenic pressure since the late 18th century, resulting in the complete loss of any remnants of the natural vegetation that previously existed there. This provides an explanation for the low naturalness of the plant communities present in Ivan Starov Square. A negative correlation was identified between hemeroby and naturalness in both urban parks. This result is relatively unremarkable (Podpriatova et al., 2023) as hemeroby is sometimes seen as the opposite of naturalness (Angermeier, 2000). The varying degrees of correlation in park plantings are worthy of further examination. In this regard, the plant communities of Ivan Starov Square exhibit a greater level of hemeroby than those of Students' Park do, despite the latter displaying a greater degree of naturalness. Moreover, there is a pronounced correlation between hemeroby and naturalness ($R^2 = 0.88$). The relationship between hemeroby and naturalness in Students' Park is much weaker ($R^2 = 0.24$). It can be posited that in circumstances of elevated hemeroby, the variables that shape the diversity of hemeroby are also responsible for influencing the naturalness of plant communities. A reduction in hemeroby may occur independently of changes in the naturalness of the community, potentially due to a distinct set of factors influencing both hemeroby and naturalness. The phenomenon of hemeroby is considered an integral consequence of anthropogenic disturbance to the ecosystem (Hill et al., 2002).The results obtained demonstrate that this hypothesis is entirely consistent with the experimental findings observed in the case of Ivan Starov Square. The term 'naturalness' is used to indicate the extent to which the natural state of the ecosystem has been degraded (Winter, 2012). The observed pattern can be explained by the notion that naturalness is seen as the result of the historical development of the ecosystem and hemerobia is seen as the result of the current impact of anthropogenic factors (Hornschuch, Riek, 2009). It can be assumed that naturalness has much greater inertia to change over time than does hemeroby. Therefore, under conditions of low naturalness, hemeroby values ranging from high to moderate can be observed.

The estimates of light intensity derived from the phytoindication are found to be reliable predictors of the values obtained from instrumental measurements. This finding is consistent with the results indicating that the mean values of the light indicator are correlated with the relative light intensity in forests (Diekmann, 1995). Compared to those of the Ellenberg scale and the weighted average method, the regression relationships utilising the phytoindication values based on the Didukh scale and the ideal indicator method exhibit superior efficacy. The weighted average method yields biased values when the actual value of the environmental factor approaches its margin value. In urban parks, the level of light typically ranges from moderate to strong, contingent on the density and condition of the tree stand (Kunakh et al., 2021). Therefore, an accurate assessment of the lighting intensity of urban parks under high light levels is highly important, and the ideal indicator method has a clear advantage.

The degree of accuracy achieved in regression prediction increases in a manner that is asymptotic with the number of species included in the inventory. The most precise estimates of the lighting regime are obtained when the number of species in the inventory exceeds 15. Two potential explanations for this result can be considered. One potential explanation for this phenomenon may be purely statistical in nature. This is exemplified by the central limit theorem, which postulates that the precision of statistical parameter estimates increases with the size of the sample. Accordingly, an increase in the number of species included in the relevé will increase the accuracy of phytoindication assessments. The second reason can be attributed to a statistical artefact, whereby greater accuracy in regression estimates is observed in areas with higher light levels due to the lower tolerance of more light-loving plant species. Consequently, the width of the ecological niche of plants (the discrepancy between Didukh indicator values) is inversely correlated with the Ellenberg indicator values, which indicate the optimal living conditions for the species ($r = -0.53$, $P < 0.001$). Less tolerant and more sensitive species are better indicators of environmental conditions (Zettler et al., 2013). Importantly, the number of species is greater in areas with greater light intensity. This suggests that the number of species is correlated with the stenotopicity of the species. Therefore, the two processes that contribute to the accuracy of phytoindication act in conjunction, with the influence of each increasing in proportion to the level of illumination in park plantations.

As hemeroby increases, the light intensity of ecosystems increases asymptotically. This may be attributed to two factors: first, areas with greater illumination are subject to greater levels of anthropogenic transformation; second, plants tolerant of higher light levels are preadapted to higher levels of hemeroby. The peripheries of tree plantations are in proximity to urban environments, which exert anthropogenic pressure on the park ecosystems. Consequently, the level of light outside the park is considerably greater due to the sparse vegetation cover, thereby establishing a correlation between the level of light and hemeroby induced by the edge effect. Plants exhibit morphological and ecological adaptations in response to light levels. For example, heavier seeds are more prevalent in annual weeds from more shaded habitats (Otte et al., 2006). The L-numbers of perennial grasses are negatively correlated with the germination rate, as biotopes with high light intensity are prone to drought, so slow germination increases the risk of plant desiccation (Bartelheimer, Poschlod, 2016). Thus, for the 128 plant species from the studied parks, the L-numbers were positively correlated with the hemeroby index ($r = 0.42$, $P < 0.001$) and negatively correlated with the naturalness index ($r = -0.32$, $P < 0.001$). A similar pattern was found for 1753 species of regional flora. The L-numbers of regional flora species were positively correlated with the hemeroby index ($r = 0.20$, $P < 0.001$) and negatively correlated with the naturalness index ($r = -0.15$, $P < 0.001$). Thus, light-loving plant species are more adapted to greater hemeroby. This result is in line with the conclusions obtained in the synthesis (Williams et al., 2015).

Conclusion

The assessment of the light regime of urban parks represents a significant challenge for the management of ecosystem functions within the context of urban green spaces. This challenge is particularly pertinent considering the need to minimise the negative effects of global climate change and climate change on the urbanisation gradient. The phytoindication approach is a widely used method for assessing environmental factors under natural and seminatural conditions. The findings of the study demonstrate that the utilisation of the phytoindication approach enables the precise estimation of light intensity in urban parks when the number of species included in the description exceeds 15. It is crucial to ensure high accuracy of assessment under high light levels to facilitate the application of this method in urban parks. The method of the ideal indicator for evaluating the ecological regime yields superior outcomes reliant on the weighted average methodology. The increase of light intensity in urban parks is concomitant with an increase of hemeroby and a decrease of naturalness.

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